Preview

- Control of Systematics with SNAP
  - ♢ Minimizing Systematics Inherent to the Experiment
  - ♢ Accounting for Changes in SN Explosion Initial Conditions ("Evolution")
  - ♢ Intergalactic Dust: Status and Correction
- SNAP Data Product and Calibration
  - ♢ Search region and strategy
  - ♢ Photometry & Spectroscopy datasets
  - ♢ Calibration
- Comparison with Alternative Facilities
  - ♢ What are the Alternatives?
  - ♢ Can alternatives perform SNAP Baseline Mission?
  - ♢ Ground-based limitations elaborated

Control of Systematics with a Dedicated SN Mission

- Current Identified Systematics
  - ◇ *Statistical uncertainties now only 2× larger than Identified Systematics.*
  - ◇ *Identified Systematics greatly decreased or become Statistical with SNAP.*
- Accounting for "Evolution"
  - ◇ *Stretch seems to account for most variation among SNe.*
  - ◇ *Additional variation constrainable by properties not currently measured.*
  - ◇ *A dedicated SN mission like SNAP can measure these initial conditions.*
  - ◇ *These signatures can be used to match high-z with low-z from same dataset.*
  - ◇ *A complete & homogeneous dataset may allow improved corrections.*
  - ◇ *Host galaxy properties provide complementary way of matching SNe.*
- Intergalactic (Gray?) Dust
  - ◇ *Any such dust must re-emit in far-infrared.*
  - ◇ *Currently galaxies can account for most of relavent FIRAS detection.*
  - ◇ *Early SNe II over $UV \rightarrow NIR$ are $\sim BB$ and can give $A(z, \lambda)$.*
  - ◇ *Dust inconsistent with most cosmological parameter combinations.*

Identified Systematic Uncertainties become Negligible or Statistical Uncertainties

Systematic	Current δM	Requirement to satisfy $\delta M < 0.02$
Malmquist bias	0.04	Detection of every supernova 3.8 magnitudes below peak in the target redshift range
K-Correction and Cross-Filter Calibration	0.03	Spectral time series of representative SN Ia and cross-wavelength relative flux calibration
Non-SN Ia Contamination	< 0.05	Spectrum for every supernova at maximum covering the rest frame Si II 6150Å feature
Milky Way Galaxy extinction	< 0.04	SDSS & SIRTF observations; SNAP spectra of host Galactic subdwarfs
Gravitational lensing by clumped mass	< 0.06	Average out the effect with large statistics with $\sim$ 75 SNe Ia per 0.03 redshift bin. SNAP microlensing measurements.
Extinction by "ordinary" dust outside the Milky Way	0.03	Cross-wavelength calibrated spectra to observe wavelength dependent absorption

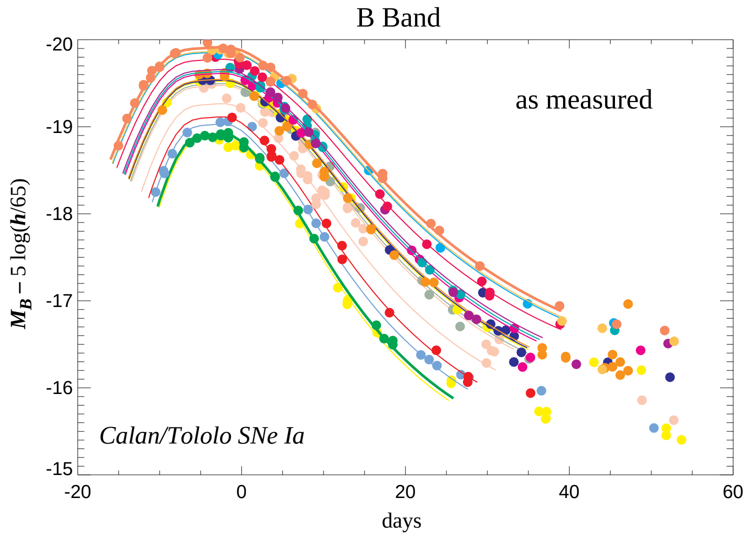
The Concept of Supernova "Evolution"

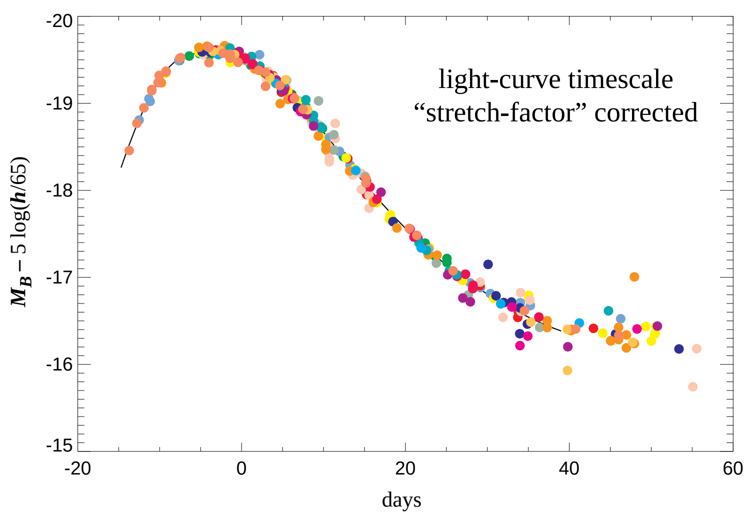
- Type Ia SNe progenitors can't all be the same:
  - ◇ *Progenitor mass affects lifetime, internal structure, and metallicity.*
  - ◇ *Metallicity at formation effects lifetime and internal structure.*
  - ◇ *Companion mass & metallicity affects timescale & accretion rate.*
  - ◇ *Binary system parameters affect timescale & accretion rate.*

These ingredients apply to SNe at all redshifts.

- Type Ia SNe explosions are not homogeneous:
  - ◇ *Progenitor properties (above) set initial conditions for explosion.*
  - ◇ *There are several candidate explosion mechanisms.*
  - ◇ *Only Chandrasekhar WD coalescence has a mass "trigger".*

If the mix of these ingredients changes with redshift, the brightnesses of the "average" SN Ia at each redshift will also differ.





Stretch-Luminosity relation appears to homogenize Type Ia Supernovae

If true, then ''average'' SN lies on Stretch-Luminosity relation, and can be corrected at any redshift

Expectations versus Observations

One might expect that : Metallicity decreases monotonically with redshift
Observations show that: Galaxies have wide range of Metallicity ($z \sim 4$ QSO's)

One might expect that : Progenitor mass increases monotonically with redshift
Observations show that: Galaxies continually form stars, so range of mass replenished

One might expect that : Age of SNe decreases monotonically with redshift
Observations show that: Galaxies continually form stars, so age range is replenished (but max age could be up to $2\times$ shorter by $z \sim 1$)

One might expect that : High redshift progenitors change from "Pop II" to "Pop I"
Observations show that: Pop II fraction low so SN rates would plummet — they don't

None of the ingredients change in sychronization with redshift. Thus, if they are important, SNe Ia dispersion must increase.

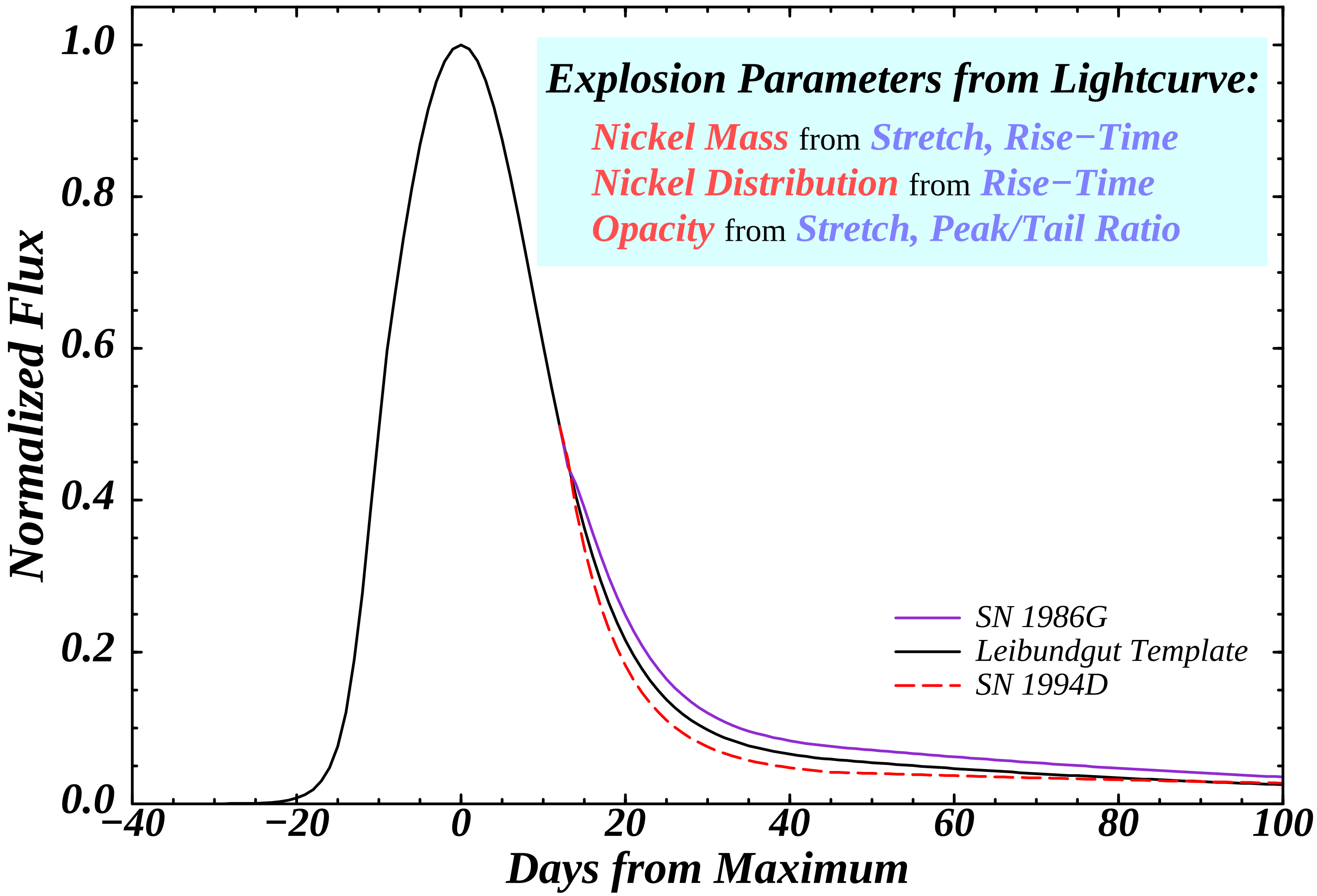
However, none of these Indirect Arguments is Essential

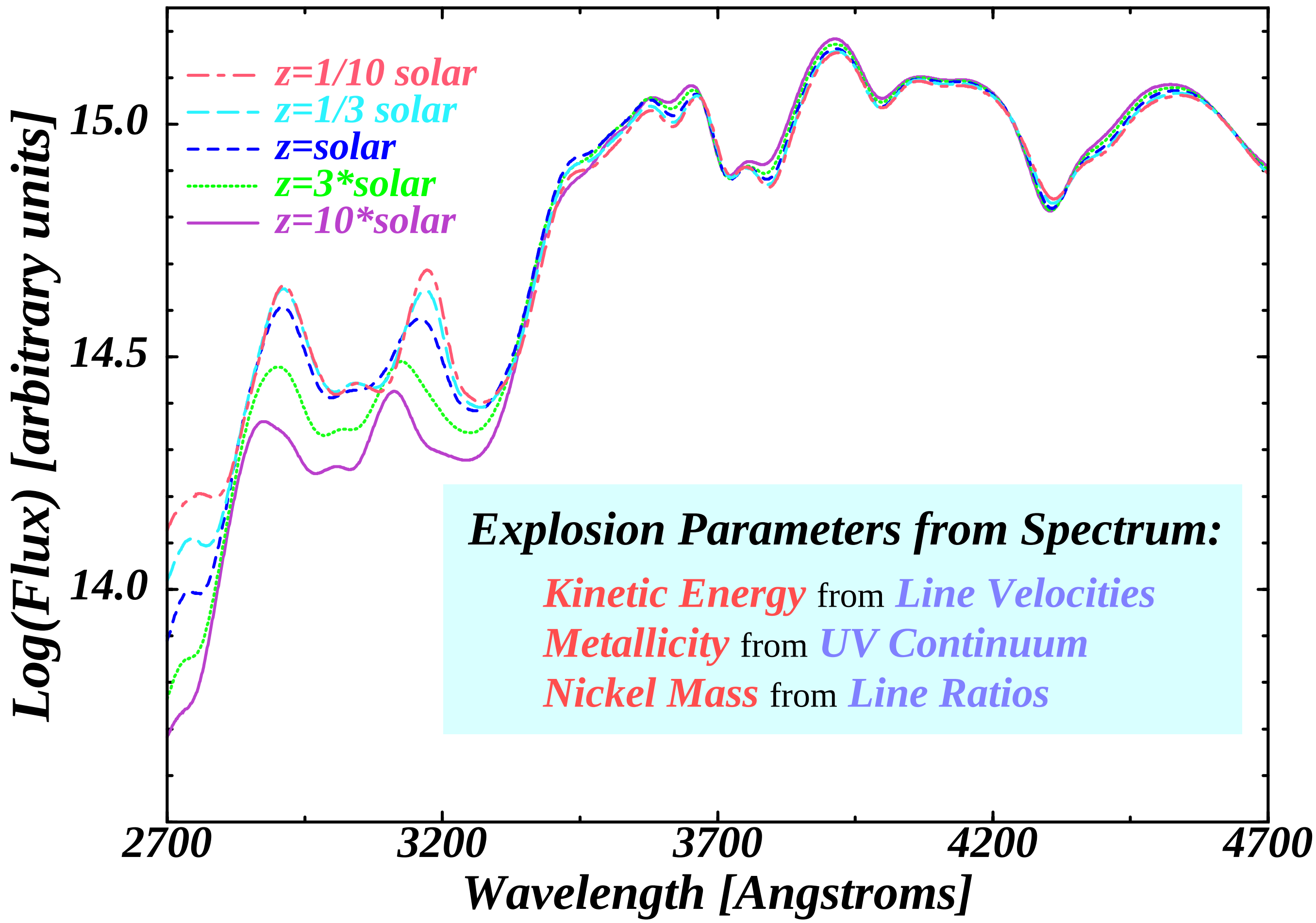
Unlike the ancient Greeks, we conduct experiments!

SNAP can measure the key parameters governing Ia explosions.

These measurements can be used to match high-z and low-z SNe.

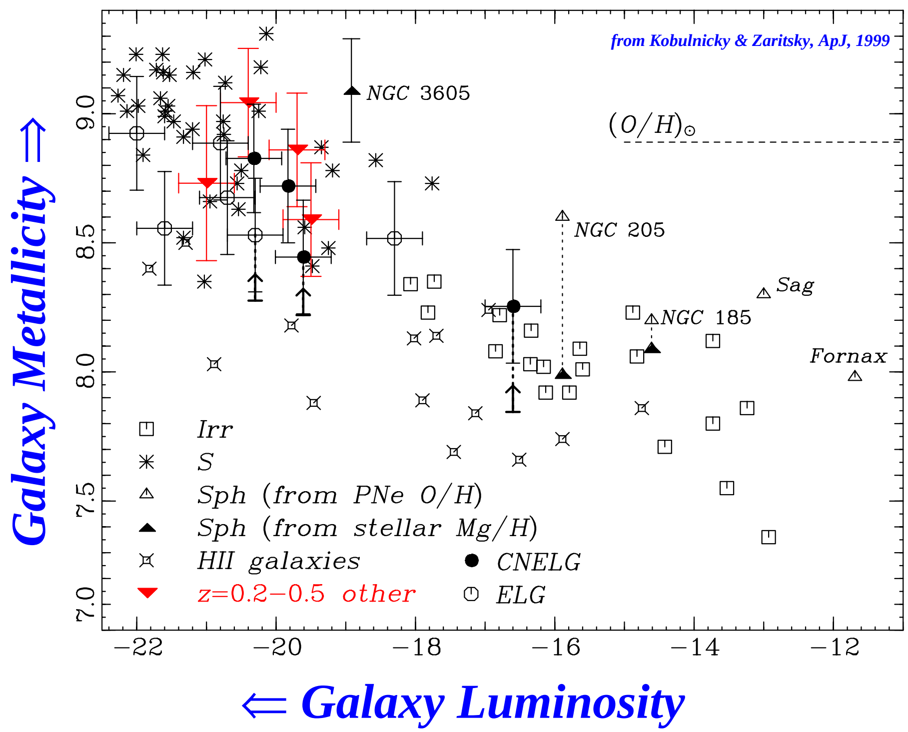
They may even reveal better ways to standardize SNe Ia.


Explosion Parameters from Lightcurve:
Nickel Mass from Stretch, Rise−Time
Nickel Distribution from Rise−Time
Opacity from Stretch, Peak/Tail Ratio
Normalized Flux
Days from Maximum
1.0
0.8
0.6
0.4
0.2
0.0
−40
−20
0
20
40
60
80
100
SN 1986G
Leibundgut Template
SN 1994D



z=1/10 solar
z=1/3 solar
z=solar
z=3*solar
z=10*solar
Log(Flux) [arbitrary units]
15.0
14.5
14.0
2700
3200
3700
4200
4700
Wavelength [Angstroms]
Explosion Parameters from Spectrum:
Kinetic Energy from Line Velocities
Metallicity from UV Continuum
Nickel Mass from Line Ratios

Galaxy Properties as Surrogates for Progenitor Properties



Galaxy ***luminosity, color, morphology, absorption*** *&* ***emission line strengths*** *- both global and local to the Supernova - are indicators of progenitor* ***metallicity*** *&* ***age.***

Thus, host-galaxy properties can be used to match SNe.

Spectrum & Lightcurve Reveal Explosion Initial Conditions

Observables	^{56}Ni Mass	^{56}Ni Distribution	Kinetic Energy	Opacity	Metal-licity
Spectral feature minima	○	—	●	○	●
Spectral feature widths	○	—	●	○	●
Spectral feature Ratios	●	—	○	○	●
Lightcurve Stretch	●	○	○	●	—
Lightcurve Rise Time	●	●	○	○	○
Lightcurve Peak/Tail	○	—	○	●	—

● = directly related to model parameter

○ = indirectly related to model parameter

— = slightly related to or no relation to the model parameter

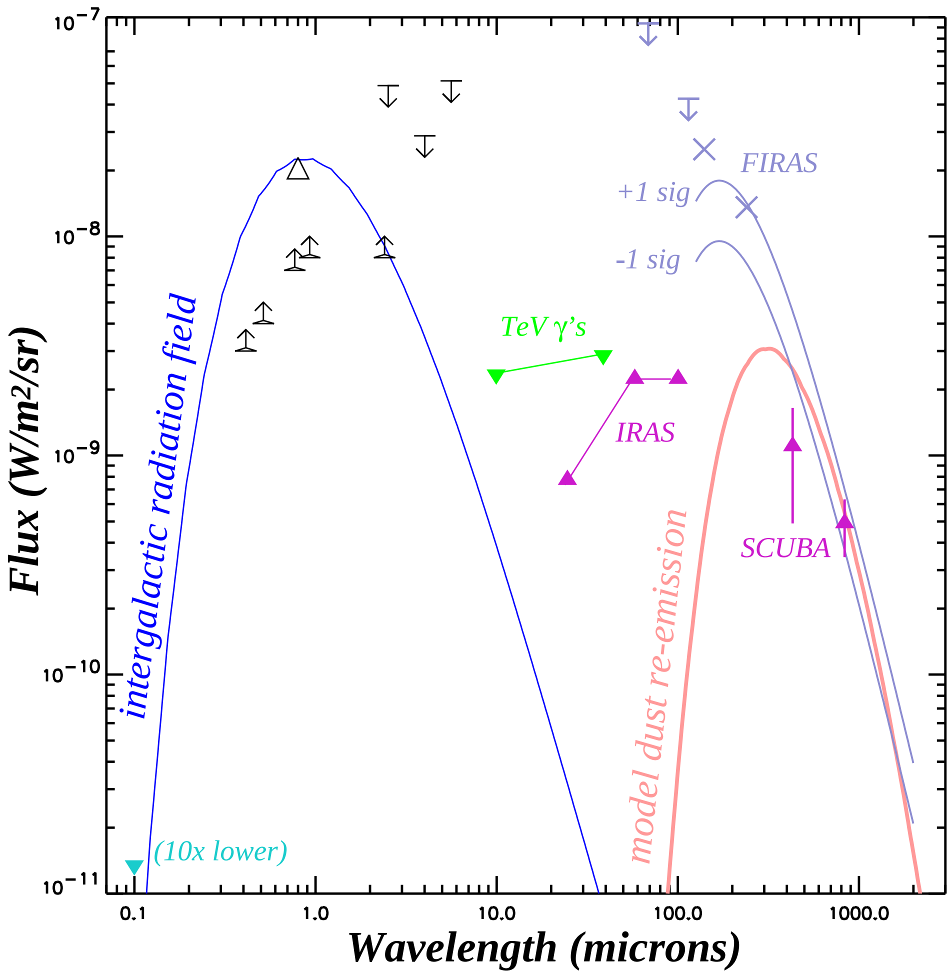
SNAP will measure all of these Observables

Accuracy to Measure Explosion Initial Conditions

Spectrum Observables X	$\partial M_{peak}/\partial X$ (rest frame)	Requirement for $m_{sys} < 0.02$
Feature minima	0.04/500 km/s	250 km/s
Feature widths	0.03/1200 km/s	500 km/s
Feature Ratios	0.12 (@B), -0.75 (@$\lambda = 3000\text{Å}$), 1.5 (@$\lambda = 6150\text{Å}$)	5%

Light Curve Observables X	$\partial M_{peak}/\partial X$ (rest frame)	Requirement for $m_{sys} < 0.02$
Stretch	0.10/5%	1%
Rise Time	0.07/1 day	0.3 days
Peak to tail ratio	0.05/0.2 mag	0.05 mag

Extinction by Intergalactic Dust is Bounded & Correctable



Galaxies ***(> 10% to 94%)***
+ IG Dust

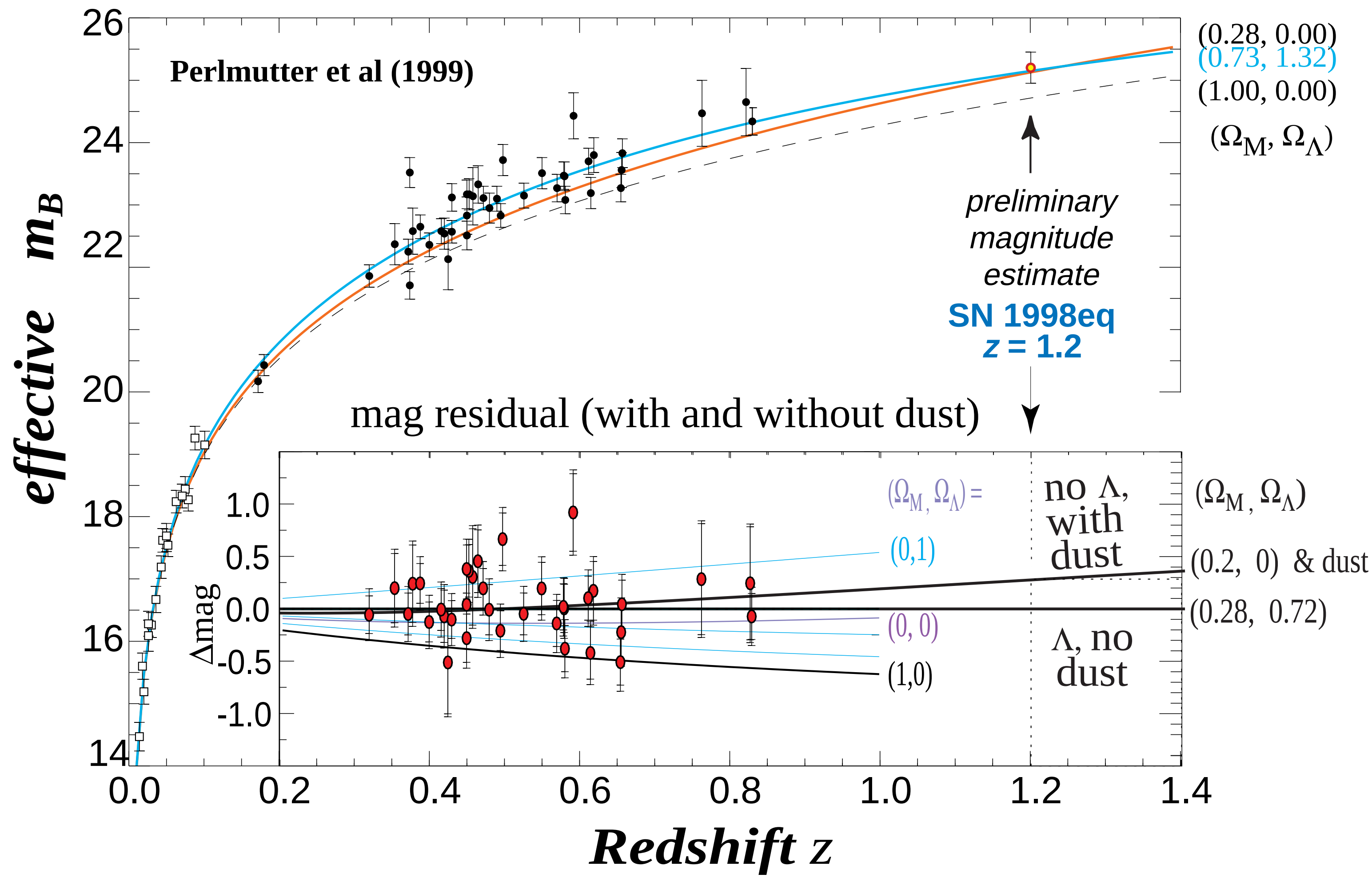
Cosmic IR Background

Large sample of Type II SNe with early UV ⇒ NIR colors from SNAP determines A(z,λ)

Perform analysis using rest-frame NIR peak flux from SNAP

IG Dust diverges from observations for most combinations of cosmological parameters

SCP SNIa at $z = 1.2$ Consistent with No IG Dust

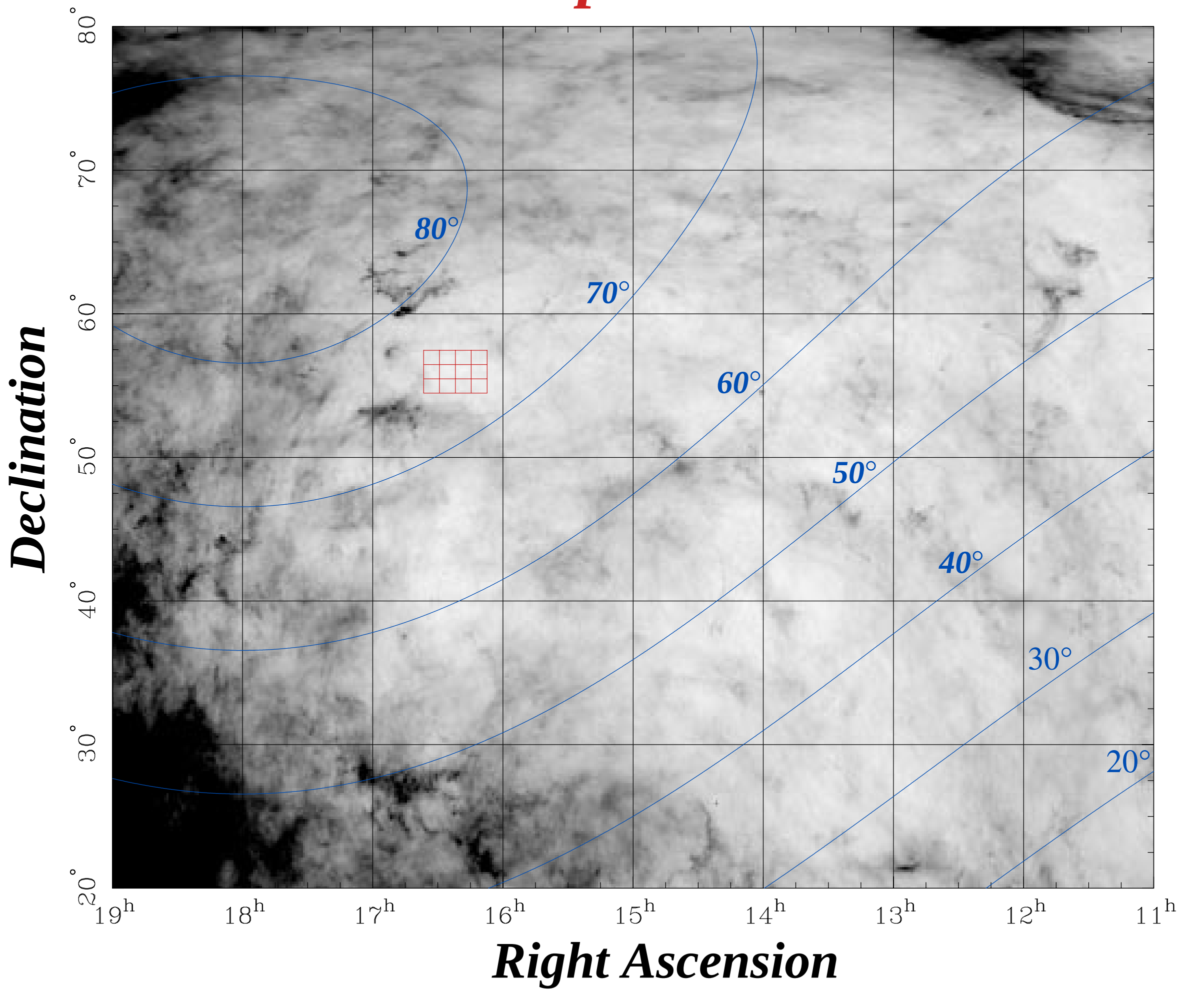


SNAP Systematics Control Summary

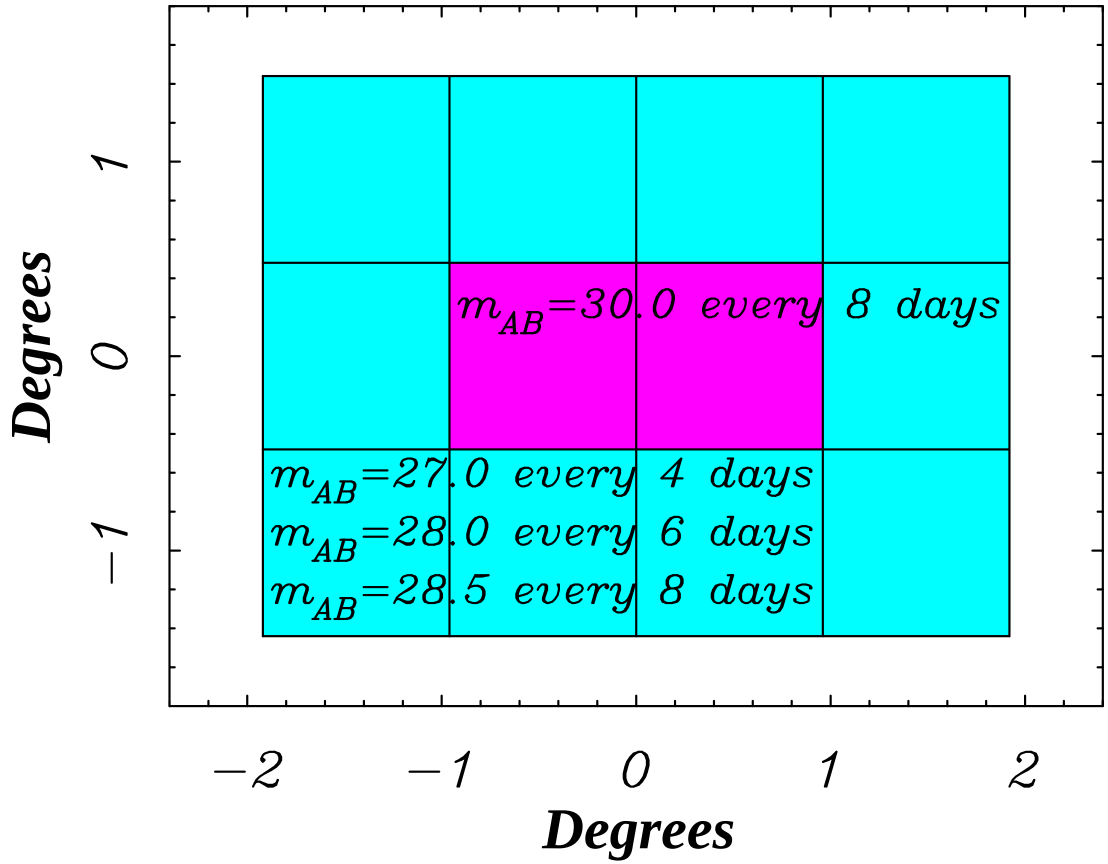
- Identified systematics become negligible or statistical
- SNe lightcurves and spectra determine initial conditions
- SNe can be matched over $0 < z < 1.7$
- SN homogenization can likely be refined with additional observables
- The amount of Intergalactic Dust can be constrained with FIR Background
- Properties of Dust with z can be measured with SNe II

SNAP can keep Systematic Uncertainties under 2%

Example SNAP Field



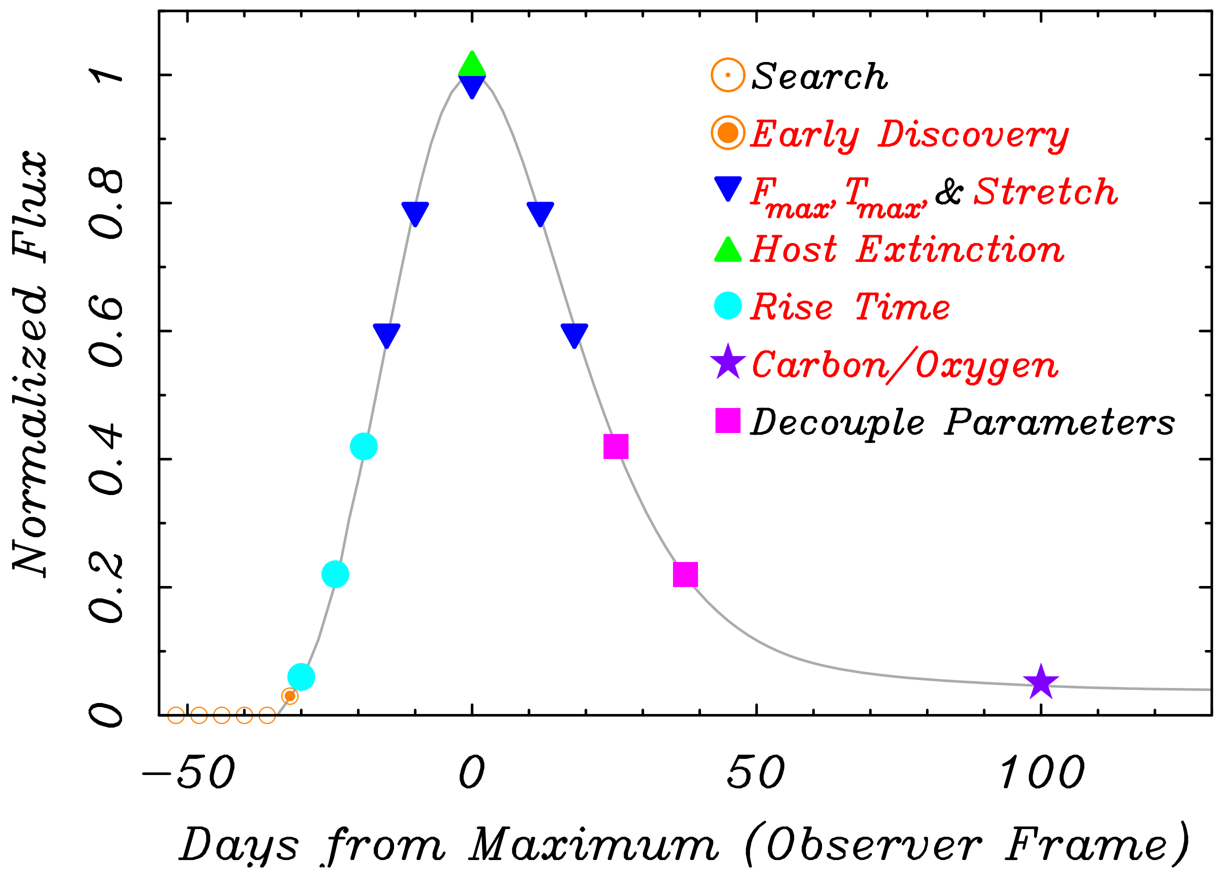
SNAP Search Strategy - Deep & Often



SNAP FOV equals:

- ***679× HST+WFPC2***
- ***507× HST+WFPC3***
- ***319× HST+ACS***
- ***225× NGST***

B−band Lightcurve Photometry for z = 0.8 Type Ia



SNAP

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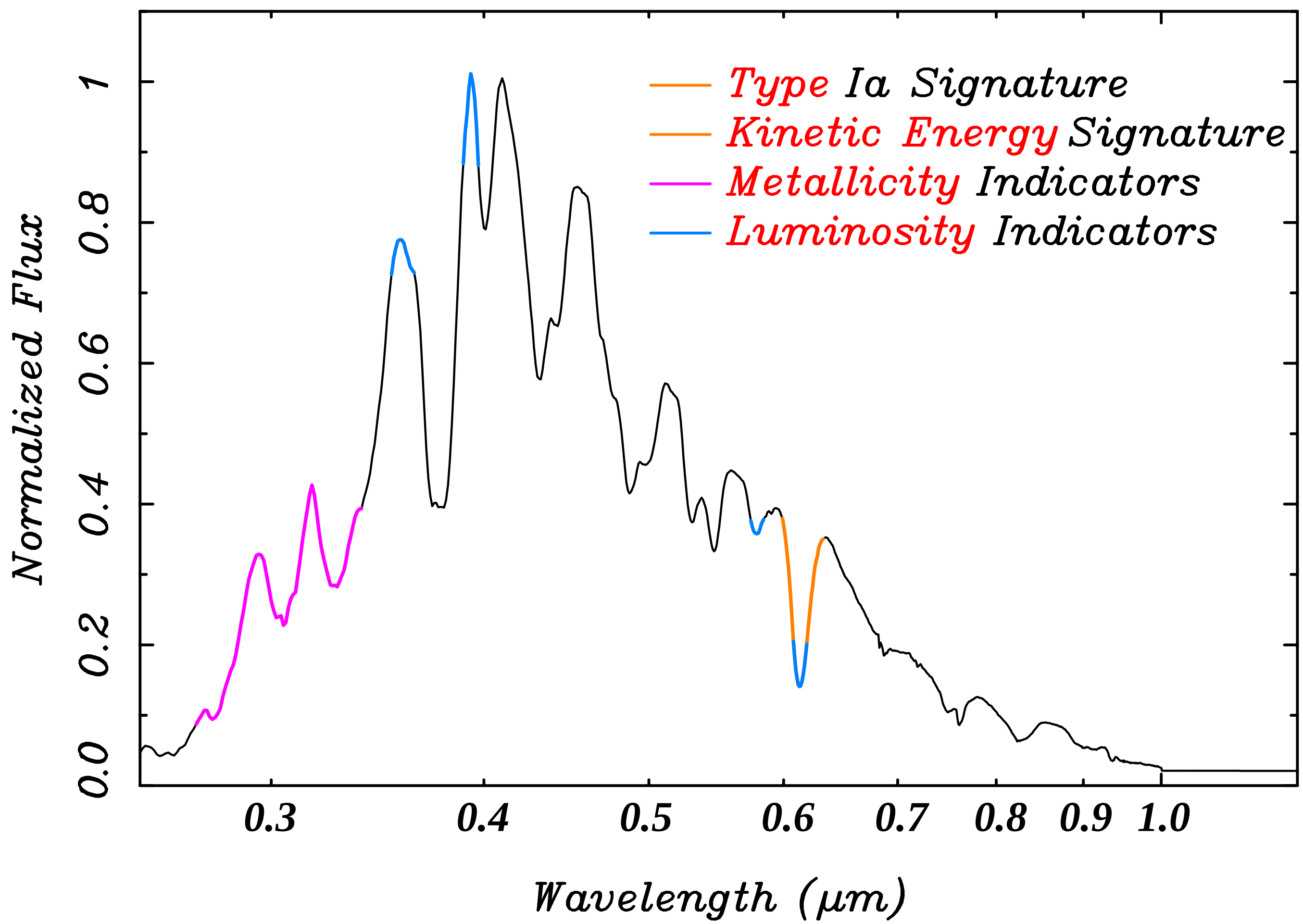
Type Ia Spectral Features



Calibration for SNAP

- CCD Imager
  - ♢ *Cleaning:* bias, dark, sky+internal flat
  - ♢ *Flux:* use existing and new (in field) broadband and spectrophotometric standard stars
  - ♢ *Point-Spread Function:* $\sim$ 10 stars per CCD available
  - ♢ *Astrometry:* wide-dithering with $\sim$ 1000 sources per CCD
- IR Imager
  - ♢ *Cleaning:* bias, dark, internal flat
  - ♢ *Flux:* in-field standard stars bootstrapped from spectrophotometric standards
  - ♢ *Point-Spread Function:* $\sim$ 10 stars per HgCdTe available
  - ♢ *Astrometry:* wide-dithering with $\sim$ 1000 sources per HgCdTe
- Spectrograph
  - ♢ *Cleaning:* bias, dark, internal flat
  - ♢ *Flux:* in-field standard stars bootstrapped from spectrophotometric standards
  - ♢ *Wavelength:* internal arcs + velocity standards
  - ♢ *Point-Spread Function:* Dense star field observations
  - ♢ *Astrometry:* Dense star field + tight-dithering

Comparison of SNAP with Alternatives

- Why not do this from the Ground?

Bright Sky and *Poor Image Quality* precludes early discovery from the ground for $z > 0.6$. Image flatness errors aggravate this problem, creating a *Wall* beyond which ground-based observations can't reach. This precludes any very faint observations, increasing *Malmquist bias*, *eliminating* constraints on explosion initial conditions from *Rise-Time* and *Peak/Tail Ratio*, and limiting the *Maximum Redshift*.

- Isn't Adaptive Optics a Solution?

AO can correct over a very small region, ~ 1 arcminute. Therefore, AO is useful for follow-up, but *Can't Be Used for Search*.

- Why not Wait and Use NGST?

$z < 1.7$ SNe are Too Easy for NGST, but they are essential for exploring the dark energy. 20 min re-pointing means NGST spends *20% of Time Observing and 80% of Time Repointing!* NGST time-sharing will stretch timeline by $\sim 10\times$. (NGST Supernova DRM searches in parallel and so has poor controls over systematics.)

Comparison Facilities & Capabilities

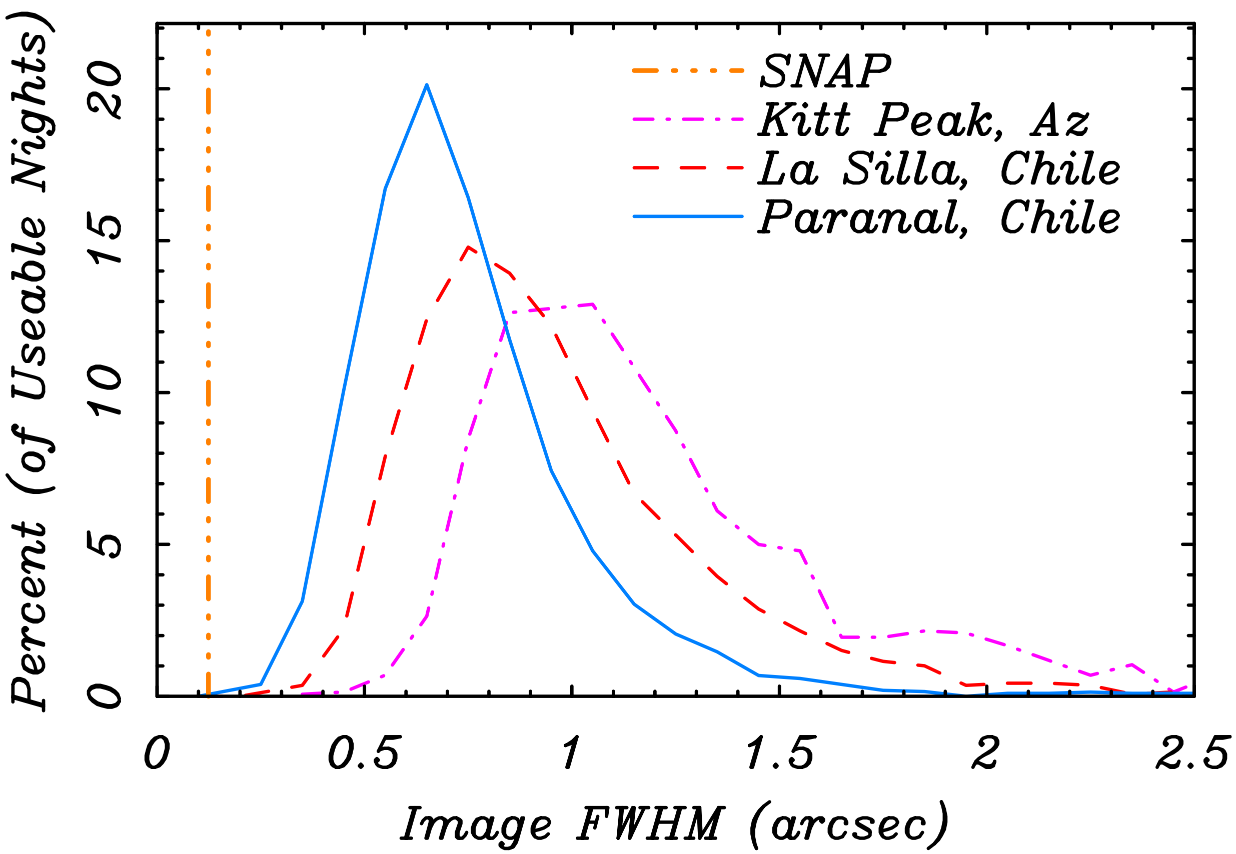
Description	Location	Aperture	FOV	AO?	OH-suppression?
CFHT	ground	3.6-m	1 □°	no	no
Keck+AO	ground	10-m	—	yes	no
WFT	ground	8-m	7 □°	no	no
OWLT	ground	24-m	1 □°	no	no
OWLT+AO+OH	ground	24-m	—	yes	yes
HST+ACS	space	2.4-m	0.003 □°	—	—
HST+ACS+NIC	space	2.4-m	—	—	—
NGST	space	8-m	0.004 □°	—	—

How Would Other Facilities Compare with SNAP?

Facilities: Search	Facilities: Photometry + Spectra	Batch Follow-Up?	SNe/yr	z Limit given time budget	Early Discovery (2 days)	Time (hrs) to Achieve S/N at max z	Mag Limit (AB)
SNAP	SNAP	Yes	2400	$z < 1.7$	Yes	4 ($S/N = 3$)	30
HST+ACS	HST+ACS+NIC	Yes	20	$z < 1.7$	Yes	2 ($S/N = 3$)	30
NGST	NGST	No	60	$z < 1.7$	Yes	0.1	—
CFHT	HST+ACS+NIC	No	350	$z < 0.6$	4 day	8 ($S/N = 5$)	26
WFT	Keck+AO	No	140	$z < 1.2$	Peak-0.5	8 ($S/N = 10$)	26
WFT	WFT	Yes	210	$z < 0.6$	Yes	6 ($S/N = 3$)	27
WFT	NGST	No	430	$z < 0.6$	4 day	8 ($S/N = 10$)	26
WFT	NGST	No	460	$z < 0.9$	6 day	7 ($S/N = 5$)	26.5
OWLT	OWLT	Yes	420	$z < 0.7$	Yes	9 ($S/N = 5$)	27.5
OWLT	OWLT+AO+OH	No	290	$z < 1.0$	5 day	4 ($S/N = 5$)	27

All comparisons attempt the SNAP baseline mission & assume 100% use of facilities.

Ground-based Searching Limited by Image Quality, and ...

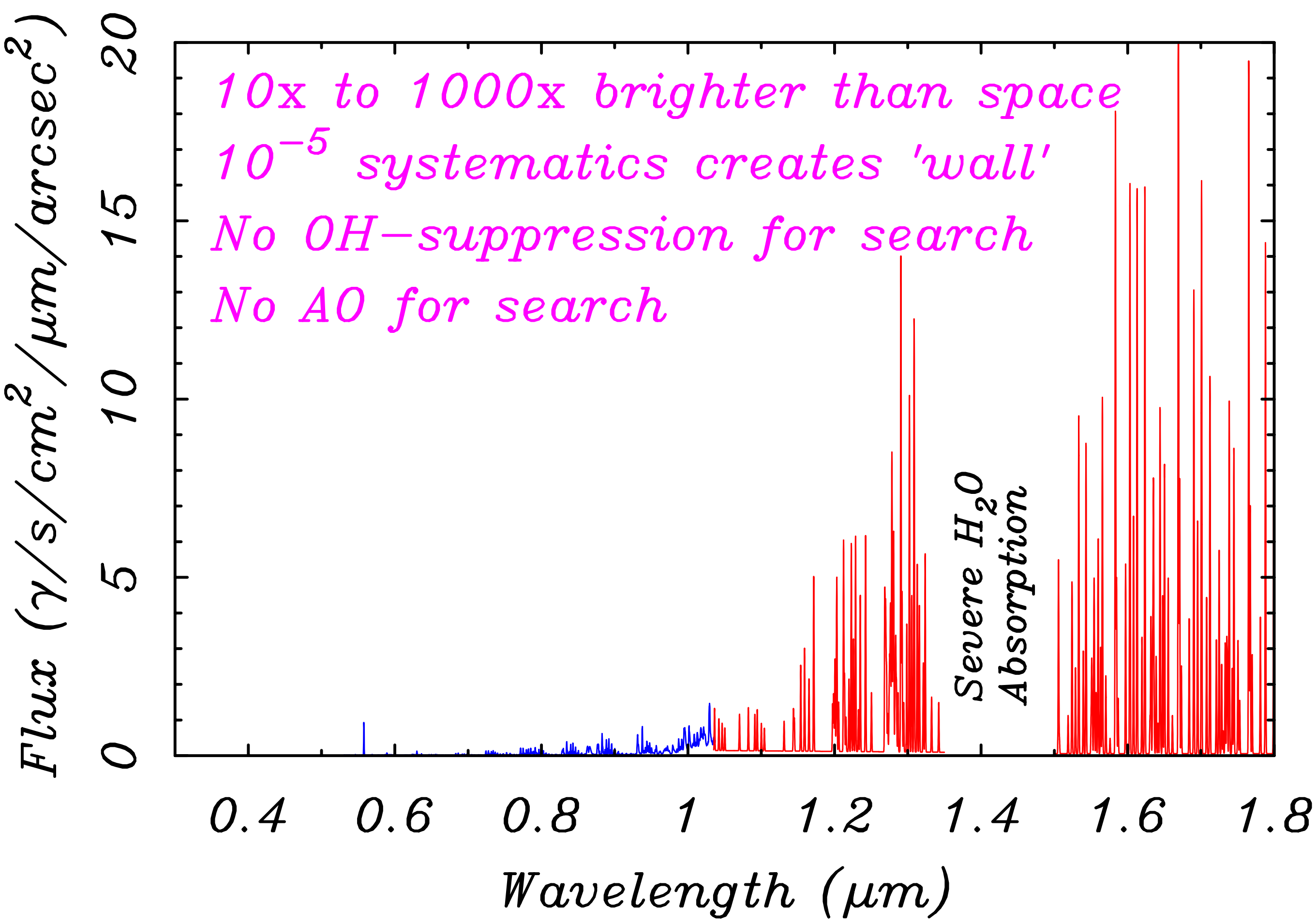


Ground-based images significantly worse so efficiency is low

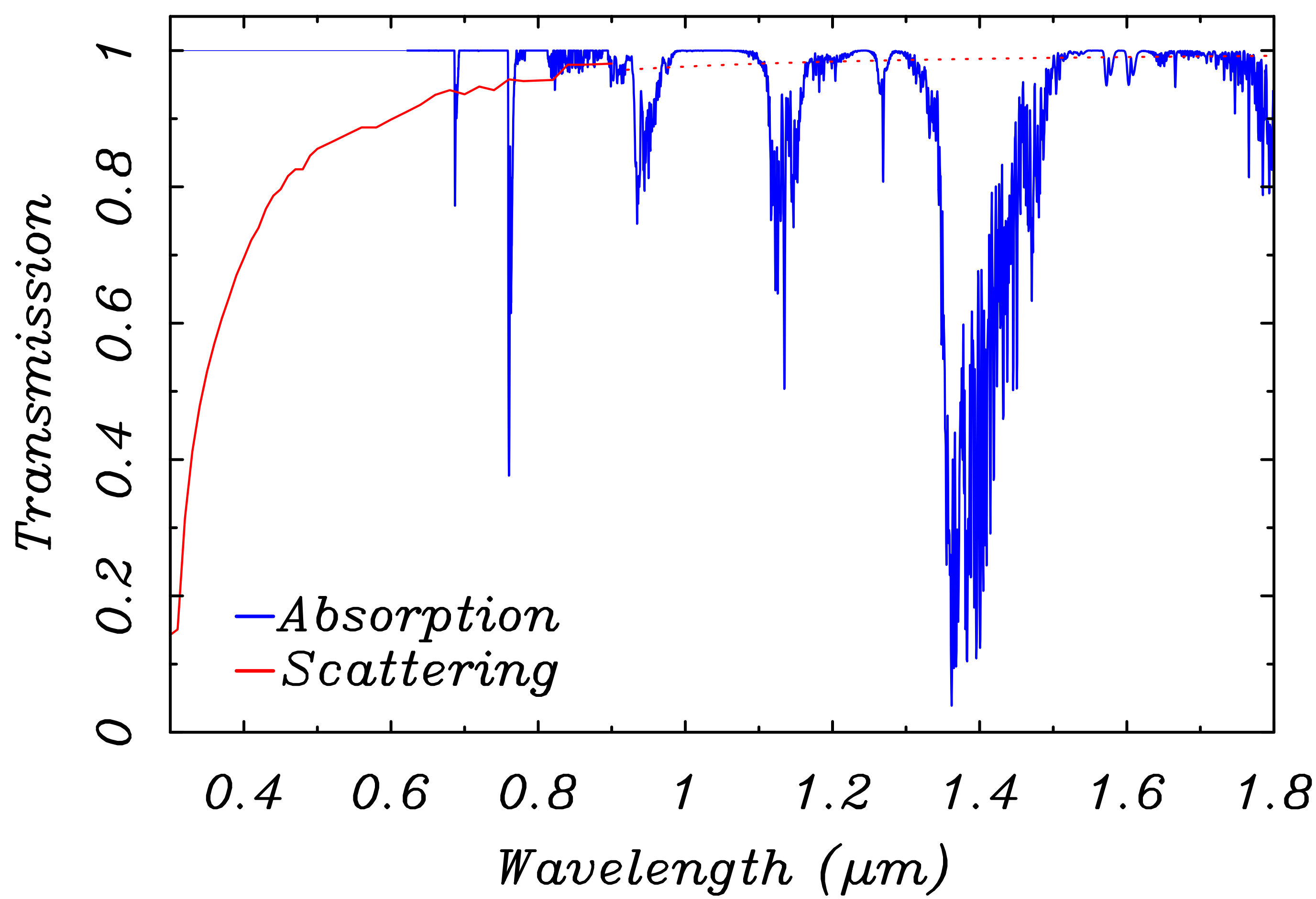
Variability compromises intra- and inter-SN homogeneity of sample

Variability leads to even greater losses in efficiency (e.g., if bad seeing develops while faint SN is observed)

the Tremendous Sky Brightness compared to SNe



Atmosphere Compromises Quality & Homogeneity



Summary & Conclusion

- SNAP provides an accurate, complete, and homogeneous dataset.
- This dataset allows unprecedented control over current and proposed systematic uncertainties.
- The SNAP dataset cannot be obtained with other reasonable combination of current or planned facilities, on the ground or in space.

SNAP is an ideal mission for making Supernovae one of the Pillars of Observational Cosmology.